Robust Digital Watermarking to JPEG Compression

Hye-Joo Lee† and Ji-Hwan Park††

ABSTRACT

Digital watermarking has been considered as an important technique to protect the copyright of digital content. It is essential that a watermark embedded in a still or moving image resists against various attacks ranging from compression, filtering to cropping. In particular, as JPEG is a dominant still image compression standard for Internet applications, digital watermarking methods that are robust against the JPEG compression are especially required. Most digital watermarking methods proposed so far work by modulating pixels/coefficients without considering the quality level of JPEG, which renders watermarks readily removable. In this paper, we proposed a new digital watermarking method as follows. For providing the robustness against JPEG, the quality level of JPEG is used as parameter on watermarking so as to compute the loss of image caused by JPEG compression and we compute the difference of an original image resulted from JPEG compression. Also in proposed method, we compute the visual components that are derived from the information of edge within image and consideration of brightness discrimination which is one of human visual system's properties. Thus, we proposed new watermarking scheme that after constructing a watermark by considering the loss of image resulted from JPEG compression and the visual components derived from the human visual system, the watermark is embedded into the image.

JPEG 압축에 견고한 디지털 워터마킹

이혜주† · 박지환††

요 약

디지털 워터마킹은 디지털 컨텐츠의 저작권을 보호하기 위한 중요한 기술로 취급되어 오고 있다. 삽입되는 워터마크는 압축, 필터링에서 cropping에 이르기까지 다양한 공격에 대하여 견고하여야 한다. 특히, JPEG은 인터넷 응용을 위한 뛰어난 정지 영상 압축 표준이기 때문에 JPEG 압축에 견고한 디지털 워터마킹 기법이 특별히 요구된다. 지금까지 제안된 대부분의 디지털 워터마킹 기법은 JPEG의 품질 수준(quality level)을 고려하지 않고 픽셀이나 계수를 변조하여 처리한다. 이것은 워터마크의 제거가 쉽게 이루어진다. 본 논문에서는 JPEG 압축 시에 발생되는 영상의 손실을 계산하기 위해 JPEG 압축의 품질 계수를 워터마크 삽입 시의 파라메터로써 이용하여 JPEG 압축에 의한 차를 계산한다. 인간 시각의 성질 중에서 밝기 차의 식별력을 고려함과 동시에 영상의 에지 정보를 이용한 시각 성분을 계산한다. 이와 같이 JPEG 압축에 의한 영상의 손실과 인간의 시각 성질을 고려한 워터마크를 구성한 후에 영상에 삽입하는 새로운 디지털 워터마킹 기법을 제안한다.

1. Introduction

The tremendous development in data compression methods has resulted in the widespread use of digital data such as image, audio and video in every corner of our daily life. Digital data are easy to distribute and duplicate. This gives rise to a serious problem in illegal copying. While encryption is essential to the provision of confidentiality, the same technology does not represent an ideal solution to copyright protection, simply because any user who possesses a decryption key may (re-)distribute

† 부경대학교 전자계산학과 졸업(박사)
†† 부경대학교 컴퓨터멀티미디어공학부 부교수, 종신회원

decrypted digital images as he or she wishes. This indicates the necessity of embedding information on the rightful owner into an image in such a way that the information and the image cannot be easily separated. To achieve this goal, researchers have proposed to use so-called digital watermarking[1,2]. The most important requirement of digital watermarking is that embedded watermarks are robust against compression, filtering, cropping, geometric transformation and other attacks. For images that are published on the World-Wide Web (WWW), robustness of watermarks against the JPEG compression standard is particularly important.

In this paper, we propose a method that constructs a watermark by using the quality level of JPEG as a parameter. As a result we obtain a watermarking method that is robust against the JPEG compression. We describe an overview of digital watermarking in Section 2. This is followed by a detailed description of our proposed method in Section 3. A number of simulation results are provided in Section 4 to verify the effectiveness of the proposed method.

2. Digital Watermarking Method

Digital watermarking consists of a pair of matching procedures, one for embedding a watermark into a still or moving image and the other for detecting/extracting the watermark. A number of factors have to be considered while embedding a watermark. These factors include the structure of a watermark, locations where the watermark is embedded, and the level of change in the quality of the image introduced by digital watermarking.

The structure of a watermark generally falls into one of two types. The first type is essentially a random binary sequence which is composed of either 0 and 1 or -1 and 1[3-6]. The second type is a random real number that is distributed according to N(0,1)[7]. With a random binary sequence, one can apply the sequence in the extraction of an embedded watermark as well as the detection of the presence of the watermark. A disadvantage of the use of a random binary sequence is that the watermark is vulnerable to such attacks as removal and collusion. In comparison, with a random real number, one cannot extract exactly the original watermarks. Nevertheless, this method has the advantage of being more robust against removal and collusion attacks, primarily due to the fact that even though an attacker may have some knowledge on the locations of a watermark, he or she has far greater difficulties in identifying the exact watermark. Random real numbers are being used by researchers more often than random binary numbers recently.

Locations for embedding watermark are often determined by using random sequences together with human visual system(HVS)[8,9]. For instance, the Podilchuk-Zeng method[8] have utilized the visual model developed by Watson[10] for the JPEG compression. More specifically, the authors have used the frequency sensitivity portion of the model to embed a watermark. In addition, Dittmann et al[9] have developed a robust video watermarking method based on a combination of an error correction code, the Zhao-Koch method[11] in the frequency-domain and the Fridrich method[12] in the spatial-domain. The method proposed in this paper is similar to the above two methods in the use of the HVS. However, as our method embeds copyright information in the spatial domain, it differs from the Podilchuck-Zeng method that embeds in the frequency-domain using DCT or wavelet transform. Compared with the method by Dittmann et al, their method doesn't consider the re-compression of a watermarked video image.

With a method entirely relying on a secure random sequence to determine locations for embedding a watermark, the quality of a watermarked image degrades since it does not fully consider the feature of the image. In contrast, by using HVS in deciding locations, it is possible to make the change of

image perceptually unrecognizable. Nevertheless an attacker who is familiar with HVS may still be able to estimate the location of the watermark. For this reason, the use of HVS actually decreases the secrecy with respect to the watermark's locations even though it meets the requirement of invisibility.

In view of these observations, we argue that digital watermarking should satisfy the following conditions:

1) If the structure of a watermark is a binary random sequence, the magnitude of the watermark has to be different in all pixels.
2) If locations to embed the watermark are random, the magnitude of the watermark has to be dependent on the image.
3) If it employs HVS, locations to embed the watermark have to be random.

In the following section, we describe our proposed method that converts a text on copyright information into binary random sequences. To satisfy the above conditions, the embedding locations and changes in pixels are determined by using the HVS.

3. Digital Watermarking Using Difference

The JPEG algorithm is one of the loss compression methods for still images. We consider a situation where a watermarked image will be compressed using the JPEG prior to its publication on WWW. Figure 1 illustrates the block diagram of the JPEG algorithm.

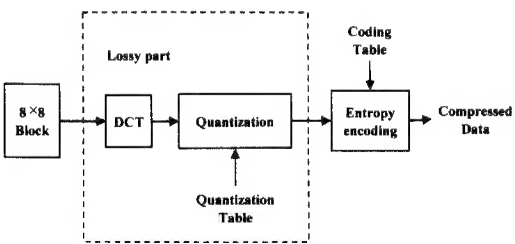


Figure 1. The JPEG compression

As illustrated in Figure 1, the loss of information is due to quantization. When the JPEG algorithm is performed, *the quality level* is used to construct a quantization table. In general, the higher the quality level, the lower the compression ratio. Now consider a case where users uses only JPEG for compression. When the owner of an image expects to achieve robustness at least for the quality level q_1, he or she can construct a watermark, and embeds it into the original image by using q_1 as a parameter. We will show how this can be done. In addition we will show that it is possible for the owner to extract the watermark from the watermarked image when the watermarked image is compressed with JPEG at a higher quality level $q_2(>q_1)$ [13].

3.1 Preprocessing

To start the method we construct a watermark as follows. We calculate the differences between the original image and a reconstructed image after compression with q_1, and the visual component from the original. Each parameter is defined as follows.

- i, j : denote one position of pixels on the original image of size $N \times M$, $0 \le i < N$, $0 \le j < M$
- h, v: denote indexes of a 8×8 block which is partitioned from the original image, $0 \le h < N/8$, $0 \le v < M/8$
- k, l : denote positions within one block, $0 \le k < 8$, $0 \le l < 8$.

First, an image I of size $N \times M$ is partitioned into 8×8 blocks. Subsequently, DCT transform is applied to each block and all DCT coefficients are quantized by quantization factors obtained from q_1. This procedure is proceeded as illustrated in Figure 2.

In Figure 2, Q.T is a quantization table derived from the quality level q_1, IQ and IDCT is inverse

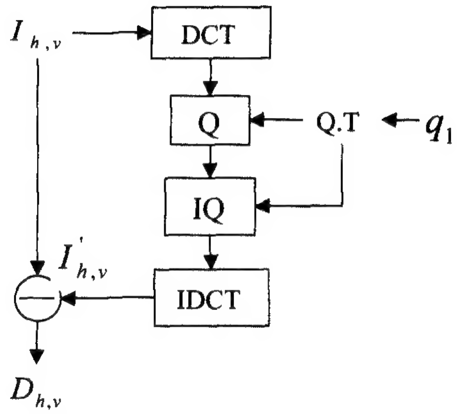


Figure 2. The computation procedure of difference

quantization and inverse DCT, respectively. Note that the quality level q_1 acts also as an indicator of robustness against the JPEG compression. For the reconstructed image, the difference $D_{h,v}$ of all blocks is calculated using Eqn.(1)

$$D_{h,v} = [\ d_{k,l}\ ],\ d_{k,l} = x_{k,l} - x'_{k,l}, \qquad (1)$$

where $x_{k,l}$ and $x'_{k,l}$ denote the value of a pixel in the original image and the value of a reconstructed pixel with respect to q_1. The difference value $d_{k,l}$ is used to decide the magnitude of a watermark to be embedded, and this magnitude is then used to obtain the watermark patterns.

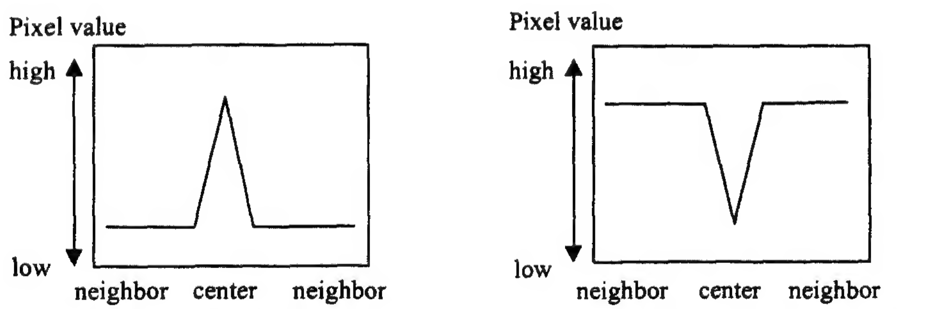
The next step in preprocessing is to compute visual components that are dependent on the image. It is difficult to perceive the change by human eyes, when some change takes place in the vicinity of edge. As considering the relation between a central pixel and neighboring pixels, types of edge are classified into two different types, as illustrated in Figure 3. Figure 3(a) represents that the central pixel is brighter than the neighboring, and Figure 3(b) indicates the opposite, namely, the neighboring pixels are brighter than the central one on average. All of these cases indicate some edges in images. Therefore it proceeds the next procedure to compute the visual components that construct watermarks by searching for the edges in image.

First, the edges in image are indicated by the average difference for a brightness between the central and neighboring pixels. That is to say, the edges occur in areas where the difference of brightness is large. Centering the pixel value $x_{i,j}$ within $t \times t$ window where a value of t is odd, the average difference of brightness is computed as

$$\hat{x}_{i,j} = \frac{1}{t^2-1}\left(\sum_{s_1=i-\frac{t}{2}}^{i+\frac{t}{2}} \sum_{s_2=j-\frac{t}{2}}^{j+\frac{t}{2}} |x_{s_1,s_2} - x_{i,j}| \right), \qquad (2)$$

where s_1 and s_2 denote indexes in window. As a result of Eqn.(2) doesn't indicate the type of edge, a relative intensity is used to determine the type of edge. The relative intensity $r_{i,j}$ is defined as the ratio of the central pixel to the average brightness:

$$r_{i,j} = \frac{x_{i,j}}{b_{i,j}}, \qquad (3)$$



(a) a case that central pixel is brighter (b) a case that neighboring pixels are brighter

Figure 3. The classification of the edge

where the value $b_{i,j}$ means the average brightness of the neighboring pixels and is computed as

$$b_{i,j}=\frac{1}{t^2-1}\left(\left(\sum_{s_1=i-\frac{t}{2}}^{i+\frac{t}{2}}\sum_{s_2=j-\frac{t}{2}}^{j+\frac{t}{2}}x_{s_1,s_2}\right)-x_{i,j}\right). \quad (4)$$

In Eqn.(3), if $r_{i,j}>1$ (i.e., $x_{i,j}>b_{i,j}$) it means that central pixel is brighter than neighboring, and hence it is of the type in Figure 3(a). Otherwise, if $r_{i,j}<1$ (i.e., $x_{i,j}<b_{i,j}$), it is of the type in Figure 3(b). A brightness discrimination is one of the human visual system's properties. This ability allows us to tell changes in brightness. In general, this ability decreases in dark area. Thus in such an area, a large change in brightness is required in order to detect the change. As the case $r_{i,j}<1$ is sensitive to the change of brightness, the change of central pixel in this case has to be determined at small value if possible. Therefore the visual components $V_{h,v}$ according to a type of edge are determined as

$$V_{h,v}=[v_{k,l}],\quad v_{k,l}=\log(r_{k,l}\cdot\ \hat{x}_{k,l}). \quad (5)$$

As shown in Eqn.(5), these components are obtained by multiplying $\hat{x}_{i,j}$ by the relative intensity $r_{i,j}$ and scaling the resulting values by taking log function, based on a fact that brightness as perceived by the human visual system is a logarithmic function of the light intensity incident on the eye.

The values $d_{k,l}$ and $v_{k,l}$, which are dependent on the image, are used to produce a watermark that satisfies the conditions 1) and 2) as mentioned earlier.

3.2 Construction of a Watermark

Before locations to embed a watermark are determined, we have to compute the magnitude of the watermark from the values of $d_{k,l}$ and $v_{k,l}$. The values of the watermark are restricted by the difference value $d_{k,l}$ through a modular operation. A pattern $U_{h,v}$ can be obtained from the product of $D_{h,v}$ and $V_{h,v}$. Note that the pattern is actually a matrix of size 8×8 (see Eqn.(6)).

$$U_{h,v}=(\ D_{h,v}\times V_{h,v}\ )\ \bmod\ D_{h,v} \quad (6)$$

It should be pointed out that the mod operation is applied to each element of the matrix. The elements $u_{k,l}$ of the matrix $U_{h,v}$ represent the amount of change in a corresponding pixel. Now the value of $f_{i,j}$ can be defined as follows.

$$f_{i,j}=\begin{cases}1, & u_{i,j}\neq0\ \text{ and }\ d_{i,j}\neq0\\ 0, & \text{otherwise}\end{cases} \quad (7)$$

The watermark is embedded into a location where the value of $f_{i,j}$ is one, that is, where the magnitude of the watermark is none zero.

Let $ID=\{id_0,id_1,\cdots,id_{l-1}\}$ be characters of ASCII format that indicates the copyright information, where $id_p\in\{0,1\}$, $0\leq p<l$ and this consists of l bits. In the following Eqn.(8), C_{ID} is obtained by repeating ID a number of times.

$$\begin{aligned}C_{ID}&=(\ \underbrace{ID\|ID\|\cdots\|ID}_{L})\\ &=(\ \underbrace{id_0,id_1,\cdots,id_{l-1}}_{l}\|\ \underbrace{id_0,id_1,\cdots,id_{l-1}}_{l}\|\cdots\|\\ &\quad\ \underbrace{id_0,id_1,\cdots,id_{l-1}}_{l}),\end{aligned} \quad (8)$$

where L is the number of locations where the value of $f_{i,j}$ is one. The repetition is necessary in order to reduce/eliminate errors during extraction. We note that clearly repetition can be replaced with a more efficient error correction code.

C_{ID} is then randomized with $m_{i,j}\in\{0,1\}$, an M-sequence with a maximum period to ensure that the condition 3) discussed above is satisfied. We denote the randomized sequences by $s_{i,j}\in\{0,1\}$ which are defined more precisely as follows:

$$s_{i,j}=\begin{cases}id_y\oplus m_{i,j}, & \text{if }\ f_{i,j}=1\\ m_{i,j}, & \text{otherwise}\end{cases} \quad (9)$$

where id_y, $0\leq y<L$ is an element in C_{ID} in Eqn.(8).

Finally a watermark pattern $w_{i,j}$ is constructed

via Eqn.(10) and it is embedded into the original image.

$$w_{i,j}=\begin{cases}(2\times s_{i,j}-1)\cdot u_{i,j}, & \text{if } f_{i,j}=1\\ 0, & \text{otherwise}\end{cases} \tag{10}$$

The watermarked image $\hat{I}$ is obtained by the addition of the pattern $w_{i,j}$ to a corresponding pixel in the original image as $\hat{I}_{i,j}=I_{i,j}+w_{i,j}$.

To extract the watermark, we subtract the original image $I_{i,j}$ from the watermarked image $\hat{I}_{i,j}$ and let a subtracted result be $\hat{w}_{i,j}$. Then, a value $\hat{s}_{i,j}$ is derived from Table 1 by comparing two signs of $\hat{w}_{i,j}$ and $u_{i,j}$ which is calculated from the original image.

Table 1. The extraction of $\hat{s}_{i,j}$

	$\hat{w}_{i,j}>0$	$\hat{w}_{i,j}<0$
$u_{i,j}>0$	1	0
$u_{i,j}<0$	0	1

To reconstruct the copyright information $\widehat{ID}$, $\widehat{id}_y$ is extracted using $m_{i,j}$ and $\hat{s}_{i,j}$ as

$$\widehat{id}_y=\hat{s}_{i,j}\oplus m_{i,j},\ \text{if } f_{i,j}=1, \tag{11}$$

where $m_{i,j}$ is equivalent to the sequence in embedding watermark. If $\hat{s}_{i,j}$ is equal to $s_{i,j}$ used in embedding, the extracted $\widehat{id}_y$ should be the same as the original id_y. As a result, all bits in the copyright information ID are reconstructed correctly by applying the majority rule to the extracted sequence $\widehat{id}_y$ as shown in Figure 4.

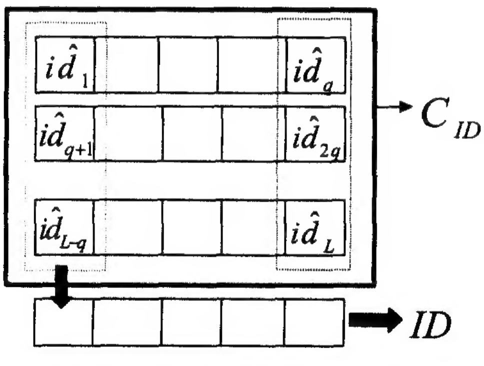


Figure 4. The reconstruction of ID

4. Simulation Results

We simulated the proposed method to evaluate the robustness of the following block data which serves as a simple example.

$$B=\begin{bmatrix}20&20&53&79&80&56&21&20\\20&82&110&110&110&110&86&22\\53&110&110&110&110&110&110&59\\79&110&110&110&110&110&110&85\\80&110&110&110&110&110&110&86\\56&110&110&110&110&110&110&62\\21&86&110&110&110&110&91&23\\20&22&59&85&86&62&23&20\end{bmatrix}$$

For the above data, the visual components can be easily calculated when the size of windows is determined as 5×5. These visual components are shown below, and indicate the edges components in a block.

$$V=\begin{bmatrix}2&2&3&3&3&3&2&2\\2&3&4&3&2&3&3&2\\3&4&3&2&2&2&3&3\\3&3&2&0&0&0&2&3\\3&3&2&0&0&0&2&2\\3&3&2&0&0&0&2&2\\2&3&3&2&2&2&2&2\\2&2&3&3&2&3&2&2\end{bmatrix}$$

In this sample block data, consider a single bit "1" as copyright information ID to be embedded into a block. The watermark pattern W for the quality level $q_1=25$ assigned in large value at vicinity of edge.

$$W=\begin{bmatrix}2&-1&-18&1&0&13&22&2\\-18&11&3&7&2&7&11&2\\2&19&0&1&1&0&-1&3\\2&12&-1&-1&1&-1&4&-10\\-2&2&-1&-1&-1&-1&-8&-9\\5&11&0&1&1&0&12&1\\-9&3&-6&9&9&-4&-2&-15\\1&-5&3&3&-2&-3&-16&1\end{bmatrix}$$

The differences and the watermark patterns for a JPEG quality level $q_1=25$ are shown in Figure 5. In Figure 5, we knows that the watermark pattern doesn't exceed the difference value with respect to q_1.

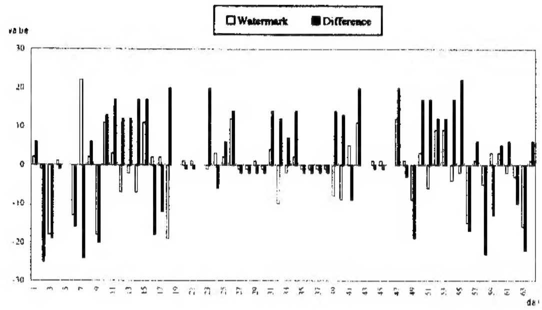


Figure 5. The difference and watermark pattern for $q_1=25$

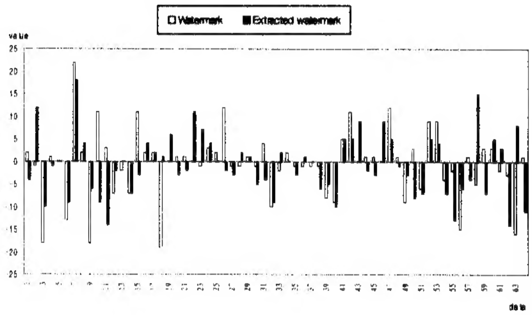


Figure 6. Extracting the watermark for $q_2=80$

The length L indicates the number of locations where the watermark is embedded. For the above data, its value is 59 out of 64. That is, 59 data among 64 are used for embedding the watermark. The results of embedding watermark is as follows.

$$B_W=\begin{bmatrix} 22 & 19 & 35 & 80 & 80 & 43 & 43 & 22 \\ 2 & 93 & 113 & 103 & 108 & 103 & 97 & 24 \\ 55 & 91 & 110 & 111 & 111 & 110 & 109 & 62 \\ 81 & 122 & 109 & 109 & 111 & 109 & 114 & 75 \\ 78 & 112 & 109 & 109 & 109 & 109 & 102 & 77 \\ 61 & 121 & 110 & 111 & 111 & 110 & 122 & 63 \\ 12 & 89 & 104 & 119 & 119 & 106 & 89 & 8 \\ 21 & 17 & 62 & 88 & 84 & 59 & 7 & 21 \end{bmatrix}$$

When these watermarked data are compressed with a quality level q_2 that is greater than q_1, we are able to reconstruct the copyright information if the signs of the extracted watermark are the same as those of the original watermark.

In another experiment we use $q_2=80$. The results are depicted in Figure 6. When compared with Figure 5, these values have corrupted due to JPEG compression. The copyright information has to be reconstructed exactly into the original one from these corrupted value.

To reconstruct the embedded single bit "1" copyright information, the embedded random sequences $s_{i,j}$ are derived from Table 1 by using the signs of the extracted watermark and pattern calculated by Eqn.(6). The $\hat{id}_y$ can be calculated from $s_{i,j}$ using Eqn.(11). The embedded ID can be reconstructed consequently by counting the number of 1's and 0's for one bit of id_y followed by the majority rule as shown Figure 4. In the simulation, the numbers of 1's and 0's are 31 and 28, respectively. This gives us "1" as the value of the embedded ID. Note that more efficient error correcting codes, rather than simple repetition, can also used.

In this example, the proposed method is able to reconstruct the copyright information with respect to $q_2=80, 75$, but not to $q_2=65\sim20$, as the size of the block is too small. In general, the larger the size of an image, the higher the chance of extraction. This motivates us to apply the proposed method to the standard image Lena(256×256, 8bits/pixel).

The original image and watermarked image are shown to Figure 7. We used $q_1=25$ as the quality control parameter, $t=5$ as the size of window to compute the visual components, and the length of copyright information is 112 bits(14 ASCII characters).

Figure 7. The original image and watermarked image for $q_1=25$

The watermarks are placed over the image and the closer in edge, the larger the watermark value as shown in Figure 8 which depicted the absolute different image between the original and watermarked image.

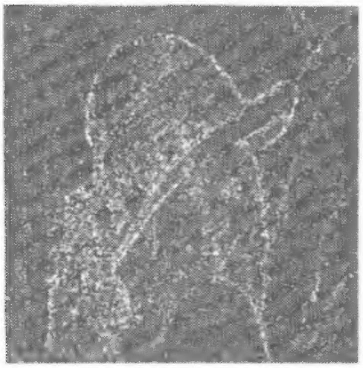


Figure 8. The absolute difference image

Table 2 indicate the numbers of 1's and 0's which are extracted from the original watermarked image that is not compressed by JPEG, for the first 10 bits "0100110000" of the 112 bits.

Table 2. The number of 0's and 1's from the extracted bits used to reconstruct *ID*

quality level q_2	bit order(the num. of 0 : the num. of 1)				
	1	2	3	4	5
80	357:187	201:343	354:190	355:189	197:347
75	329:215	219:325	343:201	339:205	213:331
60	315:229	226:318	310:234	314:230	208:336
quality level q_2	bit order(the num. of 0 : the num. of 1)				
	6	7	8	9	10
80	189:355	356:188	345:199	350:194	344:200
75	206:338	336:208	343:201	325:219	327:217
60	229:315	312:232	325:219	315:229	302:242

From Table 2, one can reconstruct correctly all the bits. But when the watermarked image is compressed by JPEG compression with a quality level of q_2 greater than q_1, the fidelity of watermarked image has degraded as compared with the original watermarked image. As a result, the embedded watermark has corrupted. Therefore, there is some mismatches between the extracted watermark and the original one. Nonetheless if the modification of extracted watermark $\hat{w}_{i,j}$ does not take place to such an extent that the sign of $\hat{w}_{i,j}$ becomes in opposite sign of the original watermark $w_{i,j}$, the copyright information may be reconstruct to original one. To verify an efficiency of the proposed method, the watermarked image was compressed with a quality level q_2 greater than q_1 and the copyright information was reconstructed, this result represented in Table 3.

Unfortunately, when the quality level q_2 ranges from 35 to 20 in Table 3, the copyright information does not reconstructed exactly. But the proposed method uses simply the repetition of the copyright information to resist an elimination or error in watermark sequence. If the efficient error correcting codes such as BCH or RS are used to construct the watermark sequence, the proposed method may be improved significantly

Many of the existing methods detect only the presence of the watermark, the proposed method is based on the watermark extraction scheme which reconstruct the watermark to original watermark again. When the extraction scheme are compared with the detection scheme, it make the owner of image clear because the copyright information is a text format that the human is understandable. Also the detection schemes must apply the theory of hypothesis test for proving the ownership of image, these schemes have false alarms, that is, type I error and type II error. Therefore we believe that the extraction scheme may be more effective than the detection method in that the obviousness of the ownership.

5. Conclusion

The proposed method utilizes the quality level of JPEG as a parameter in watermarking to provide robustness against JPEG compression. It calculates visual components using relationships with neigh-

Table 3. Reconstruction of ID after JPEG compression(when $q_1 = 25$)`

quality level q_2	reconstructed copyright information ID	reconstruction ratio
0,90, 80,70 60,50,40	010011000000011001001110000000110011001100100011 00000111000000000000000000000000000000000000 0000000000000000000000	100%
35	010011000000011001001110000000110011001100000011 00000111000000000000000000000000000000000100 0000000000000000000000	98% (110/112)
30	010011000000011001011110000000110011001100100011 00000111000000001000000000000000000000000000 0000000000000000000000	98% (110/112)
25	010011000000011001001111000001100110011001000 11 00000111000001001000000000001011000000000000000 0000000100000000000001	93% (105/112)
20	0100110000000110010011100000001100110011001000X11 11000011010000001000000100010001010000000000010 000011000000100000000	88% (99/112)

boring pixels. Locations to embed the watermark are derived from these visual components. To minimize extraction errors caused by compression, copyright information is repeated and converted into random sequences by XOR with M-sequences. As the result, the owner can extract the watermark almost even when the watermarked image is compressed, as long as the quality level is not smaller than the quality level used as a parameter. The copyright information can be reconstructed from the embedded random sequences at a later stage. There are cases that the copyright information can not be reconstructed, but these cases may be resolved by using the efficient error correcting codes such as BCH or RS.

To close this paper, we remark that in this work we have considered only the quality level of the JPEG compression algorithm as a parameter. One may use different parameters related to image processing, and these parameters might provide equal or even stronger robustness against various attacks based on image processing.

Acknowledgement:

The authors would like to thank the reviewers for their comprehensive reviews.

References

[1] M. D. Swanson, M. Kobayashi and A. H. Tewfik, "Multimedia Data-Embedding and Watermarking Technologies", In Proc. of IEEE, Vol.86, No.6, pp.1064-1087, 1998

[2] M. M. Yeung et al, "Digital Watermarking", Communications of the ACM, Vol.41, No.7, pp.31-77, 1998

[3] C. T. Hsu and J. L. Wu, "Hidden Signature in Images, In Proc. of IEEE International Conference on Image Processing", pp.223-226, 1996

[4] G. Langelaar, J. van der Lubbe and J. Biemond, "Copy Protection for Multi-media Based on Labeling Techniques", http://www-it.et.tudelft.nl/pda/smash/public/benelux_cr.html

[5] M. Kutter, F. Jordan and F. Bossen, "Digital

Signature of Color Images Using Amplitude Modulation", In Proc. SPIE-EI97, pp.518-526, 1997

[6] K. Matsui and K. Tanaka, "Video-steganography: How to Embed a Signature in a Picture", In Proc. IMA Intellectual Property, Vol.1, No.1, pp.187-206, 1994

[7] I. Cox, J. Kilian, T. Leighton and T. Shamoon, "Secure Spread Spectrum Watermarking for Multimedia", Tech. Rep., 95-10, NEC Research Institute, 1995

[8] C. I. Podilchuk and W. Zeng, "Image-Adaptive Watermarking Using Visual Models", IEEE Journal on Selected Areas In Communications, Vol.16, No.4, pp.525-539, 1998

[9] J. Dittmann, M. Stanenau and R. Steinmetz, "Robust MPEG Video Watermarking Technologies", ACM Multimedia'98, 1998

[10] A. B. Watson, "DCT Quantization Matrices Visually Optimized for Individual Images", Proc. of SPIE, 1992

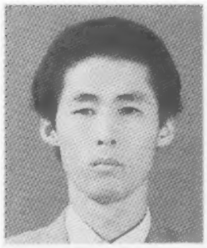
[11] E. Koch and J. Zhao, "Towards Robust and Hidden Image Copyright Labeling", Proc. of IEEE Workshop on Nonlinear Signal and Image Processing, 1995

[12] J. Fridrich, "Methods for Data Hiding", http://ssie.binghamton.edu/jirif/

[13] H. J. Lee, J. H. Park and Y. Zheng, "Digital Watermarking Robust Against JPEG Compression", Proc. of Information Security Workshop, Lecture Notes in Computer Science Vol. 1729, pp.167-177, 1999

Hye-Joo Lee

She was born in Pusan, Korea, in 1971. She received the B.S. degree, M.S. degree and the Ph. D. degree in Computer Science from PuKyong National University, Pusan, Korea, in 1994, 1997 and 2000. Her current research interests include the digital watermarking scheme, information theory and its application, cryptography and its application, image processing etc.



Ji-Hwan Park

He received the B.E. in electronic engineering from Kyunghee University, Seoul, Korea in 1984 and the M.E. degree and D.E. degree from the University of Elector-Communications and Yokohama National University, Tokyo and Yokohama, Japan in 1987 and 1990, respectively. He is currently an associate professor of the Division of Multimedia and Computer Science, PuKyong National University, Pusan, Korea. From 1990 to 1996 he was an assistant professor of the Department of Computer Science, National Fisheries University of Pusan, Korea. He was a guest researcher at the Institute of Industry Science, University of Tokyo and Monash University in Australia in 1994-1995 and 1999, respectively. His primary research interests include information theory and its application, cryptography and its application, image processing. He is a member of IEEE, Society of Information Theory and its Applications, Korea Institute of Communication Science, Korea Institute of Information Security and Cryptology, Korea Information Processing Society and Korea Multimedia Society.